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Personalized risk messaging can reduce climate concerns

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ABSTRACT

One potential barrier to climate policy action is that individuals view climate change as a problem for people in other parts of the world or for future generations. As some scholars argue, risk messaging strategies that make climate change personally relevant may help overcome this barrier. In this article, we report a large-n survey experiment on San Francisco Bay Area residents to investigate how providing spatially-resolved risk information to individuals shapes their climate risk perceptions in the context of sea-level rise. Our results suggest that personalized risk messaging can sometimes *reduce* concern about sea-level rise. These experimental effects are limited to respondents who believe that climate change is happening. Further, we do not find an effect of providing local risk messages on an individual's willingness to pay for regional climate adaptation measures. Our results emphasize that local messaging strategies around sea-level rise risks may not have the clear impacts that some advocates and scholars presume.

1. Introduction

The climate crisis continues to intensify despite growing scientific certainty and capacity to forecast climate risks. Sea-level rise, which is the substantive focus of this paper, provides an illustrative example. The causal processes linking global climate change to sea-level rise are well accepted (IPCC, 2013; Warrick and Oerlemans, 1990; Church and White, 2006), and many coastal regions across the world are already experiencing increased flooding during high tides and storm events (Sweet, 2014). Concurrently, bio-physical models have been developed to provide spatiallyresolved predictions of coastal flooding from sea-level rise under different climate change and storm scenarios (Barnard et al., 2014; Smith et al., 2010). These models suggest that sea-level rise and associated flooding will result in severe economic, social, and environmental damages (Hinkel et al., 2014) and potentially displace millions of people (Hauer et al., 2016; Meehl et al., 2005; Strauss et al., 2015).

Despite current and predicted impacts, climate change risks such as sea-level rise are often not salient to the public. Instead, many individuals in the global North view climate change as an issue that threatens distant populations and future generations, not their own communities (Leiserowitz, 2006; Lorenzoni et al., 2007; O'Neill and Nicholson-Cole, 2009; Leviston et al., 2014). These citizen risk perceptions are important for issues like sea-level rise, where adaptation may require individual behavior change as well as support for adaptation policies (Lubell, 2017).

One potential strategy to increase the salience of climate risks is to make these risks more personally relevant for individuals (Rayner and Malone, 1997; Weber, 2006; Lorenzoni and Pidgeon, 2006; Lorenzoni et al., 2007; Spence et al., 2012; Scannell and Gifford, 2013). For instance, risk messaging that emphasizes local and concrete climate impacts (e.g., how changes in temperature, precipitation, extreme events, or sea levels will affect a specific individual or community) could potentially increase support for necessary climate risk mitigation. This potential is underscored by research showing how personal experiences with climate-related impacts can change household behaviors and increase support for climate adaptation (Spence et al., 2011).

Yet, despite the ubiquity of this idea in climate advocacy debates, empirical evaluations of "personalized" risk communication strategies have yielded mixed results (Shwom et al., 2008; Spence and Pidgeon, 2010; Spence et al., 2012; Scannell and Gifford, 2013; Brügger et al., 2015a, 2016; Schoenefeld and McCauley, 2016). At the extreme, some recent research suggests such strategies can *decrease* individual risk concerns and undermine support for adaptation and mitigation policies

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(Spence and Pidgeon, 2010; Schoenefeld and McCauley, 2016). As a result, understanding whether personalized risk communications increase or decrease climate concerns is ultimately an empirical question with critical implications for policy-makers who are trying to change individual behavior and increase support for climate policy.

In this article, we analyze the impacts of personally-relevant risk messages on climate risk perceptions. More specifically, we report a large-n survey experiment on San Francisco Bay Area residents to investigate how providing local, spatially resolved sea-level rise information to individuals shapes their sea-level rise risk perceptions and their willingness to invest in climate adaptation measures. We capitalize on the fact that models of coastal hazards due to sea-level rise and storm surge are now precise enough to visualize expected flooding at a high level of spatial resolution (Barnard et al., 2009, 2014). Thus, we are able to present citizens with specific information about potential sea-level rise in their communities (defined at the zip-code level).

Our results suggest that personalized risk messaging has uneven effects on public risk perceptions. We find that providing locally-resolved sea-level rise risk information to individuals on average *reduces* concern that sea-level rise will affect them personally, even in zip codes that are projected to see at least some flooding. However, this effect is less pronounced in zip codes with higher objective flooding risks. Further, overthe entire sample, the flood map communication creates a slight increase in belief that geographically-distant individuals will be harmed by sea-level rise. Finally, our experimental effects are only present among respondents who already believe that climate change is happening. This suggests that local sea-level rise information may have corrected inflated risk perceptions among individuals with pre-existing climate concerns. However, we do not find an effect of risk messaging on an individual's willingness to pay for regional climate adaptation measures. Overall, these findings suggest the need for researchers and policymakers to undertake new research on the potential psychological and risk perception mechanisms that contemporary climate risk communication strategies may entail.

2. Background

The past decade transformed climate change from an abstract future threat into an immediate source of harm to human and natural communities, including in the United States. From coastal flooding (Reed et al., 2015) to extreme weather (Hansen et al., 2012; Mann et al., 2017) to wildfires (Abatzoglou and Williams, 2016), the signature of climate change can now be located in the lived experiences of individuals across both the global North and South. Yet, climate opinion surveys and focus groups often reveal that climate change remains a non-salient issue for the general public (Leiserowitz, 2006; Lorenzoni et al., 2007; O'Neill and Nicholson-Cole, 2009; Leviston et al., 2014). Instead, climate and environmental threats are viewed as more of a concern for socially, temporally, or spatially distant communities (Gifford et al., 2009). For instance, as of October 2017, only 50% of the US public believes that climate change will impact them; by contrast, 71% of the US public thinks climate change will harm people in developing countries (Leiserowitz et al., 2017).

One potential strategy to increase the salience of climate risks is to make these risks more personally relevant for individuals (Rayner and Malone, 1997; Weber, 2006; Lorenzoni and Pidgeon, 2006; Lorenzoni et al., 2007; Spence et al., 2012). In this context, existing research distinguishes between the effects of communicating the potential risks of climate change versus directly experiencing climate change impacts. Scholars have found that experiencing the impacts of climate change firsthand may increase the salience of climate-related risks (Akerlof et al., 2013; Spence et al., 2011; Howe and Leiserowitz, 2013; Myers et al., 2013; Lujala et al., 2015). These experiences have even increased citizens' willingness to mitigate for or adapt to climate change (McDonald et al., 2015), either by engaging in actions directly related to the event itself (e.g., restricting water usage in response to water scarcity) (Haden et al., 2012) or by participating in indirect actions (e.g., restricting energy usage after experiencing climate-induced flooding) (Spence et al., 2011). However, these shifts appear limited to groups who perceive their experiences as being climate-linked (Brügger et al., 2015b). This has led scholars to argue that lived climate experiences may raise the public salience of climate change and support the emergence of broad political coalitions behind mitigation and adaptation reforms (Lorenzoni et al., 2007; O'Neill and Nicholson-Cole, 2009).

In contrast, in areas that have not yet experienced the impacts of climate change but that are at risk of future impacts, decision makers are faced with the challenge of raising public awareness of climate risks and garnering support for mitigation or adaptation actions. Raising awareness of future risks is especially important for climate adaptation when pre-emptive measures are required to increase resilience before the climate impact occurs (e.g.; flooding and fires). Some argue that the climate threat must be made more personal by demonstrating concrete, individual-level risks to the general public. For instance, Weber (2006) argues that risk salience can be increased by providing individuals with simulations of future impacts on their communities and homes. Other scholars emphasize the importance of reducing perceptions among the public that climate change is primarily a threat for future generations or geographically distant populations (Rayner and Malone, 1997; Lorenzoni and Pidgeon, 2006; O'Neill and Nicholson-Cole, 2009; Moser and Dilling, 2007; Scannell and Gifford, 2013).

However, the empirical efficacy of these efforts to "personalize" local climate risks remains uncertain. Evaluations of efforts to make climate risks seem more individually proximate have yielded mixed results. Some studies find positive effects as anticipated. For example, Scannell and Gifford (2013) find that information on local climate impacts increased climate engagement relative to a control conditions. Relatedly, local risk perceptions appear to shape the intensity of climate issue engagement (Spence et al., 2012; Scannell and Gifford, 2013). Likewise, Brügger et al. (2016) find that fear motivates climate change engagement more in proximate conditions, though the study emphasizes the absence of any clear links between perceived threat distance and issue engagement. Other studies find null effects, with no difference in climate concerns as a function of exposure to information about local versus more distant risks (Shwom et al., 2008; Schoenefeld and McCauley, 2016). Still other studies find negative effects, suggesting that local information exposure reduces climate concern. For instance, Spence and Pidgeon (2010) find that respondents exposed to more distant climate impacts rated these as more severe than individuals receiving information about equivalent local impacts. These studies question the assumption that the barrier to climate action is the absence of salient local risks associated with climate change (Devine-Wright, 2013).

The debate about"personalizing" climate risk messaging is evident in the sea-level rise context of this paper, where governmental and non-governmental organizations have invested in tools to visualize various sea-level rise and flooding scenarios at the local level. For example, the "Surging Seas" initiative is a privately-funded effort to communicate personalized sea-level rise risks maps to the global public. The US government provides a similar visualization tool, the "Sea-Level Rise and Coastal Flooding Impacts Viewer," which was developed by the National Oceanic and Atmospheric Administration's Office for Coastal Management. Flooding risk perceptions shape adaptive responses by vulnerable communities — and scholars must pay more attention to social and contextual factors in understanding the ways in which the public engages with and responds to flooding threats (Birkholz et al., 2014). Yet, empirical efforts to study flooding risk communications remain rare (Kellens et al., 2013).

What drives these mixed results? On one hand, there may be methodological gaps in the empirical strategies used to test climate risk perceptions. Some scholars have criticized existing experiments for ambiguous treatments that do not clearly represent local risk messaging

(Devine-Wright, 2013; Brügger et al., 2016). More broadly, there are also several theoretical reasons why efforts to emphasize "local" climate risks and to personalize these risks may be counterproductive for risk communicators. Diverse social science literatures suggest at least three reasons why making climate risks personal and local may not automatically enhance public support for mitigation actions.

First, while some research on climate risks and decision-making suggests that individuals are more motivated to confront immediate and personal risks (O'Connor et al., 1999; Brody et al., 2012), other studies question whether this is necessarily the case (Haden et al., 2012). For instance, making climate concerns personal may induce fear and avoidance that can undermine action (McDonald et al., 2015; Brügger et al., 2015a, 2016) or lead to decreased issue salience if the threats are not manifested within a reasonable period of time (O'Neill and Nicholson-Cole, 2009). This potential echoes a broad literature on the potential backfire effects that stem from using fear appeals in a variety of domains (Witte and Allen, 2000). In sum, making risks personal and immediate can either increase or decrease risk management, depending on the context.

Second, people engage with potential threats via different psychological mechanisms depending on their perceived spatial, temporal, and social distance. According to construal theory, individuals draw on different mental representations of risks and prioritize different features of these representations when making decisions about proximate versus distant threats (Trope and Liberman, 2003; Liberman and Trope, 2008). Generally, distant risks are evaluated using general and abstract criteria, while proximate risks are evaluated using concrete and context-dependent criteria. Importantly, construal theory emphasizes that psychological distance and issue salience are different concepts; simple efforts to make threats local or concrete can shape cognitive understandings of risk independent of their potential effects on issue salience (Ledgerwood et al., 2010a, 2010b). It is not clear that the processes through which individuals manage more psychologically proximate threats promote risk management more than processes which support more psychologically distant threats.

Applied climate research using construal-level theory emphasizes how more complex understandings of psychological distance complicate efforts to predict the effect of personalized risk messages. Schuldt et al. (2018) confirm in an applied experiment that distance reductions make individuals more likely to describe sea-level rise in concrete rather than abstract terms, but finds no effect on policy support or issue engagement. Haden et al. (2012) find that Californian farmers are more likely to engage in mitigation behaviors when risks are understood as distant but adaptation behaviors when risks are understood as more proximate. Similarly, Brügger et al. (2015b) find that support for personal climate mitigation actions may be enhanced by proximate risk framing, while broader policy support may be increased under more distant framing. Brügger et al. (2016) find that making the climate threat more proximate to individuals increases the importance of fear-based decision-making without clearly leading to stronger issue engagement.

Third, public climate beliefs are also shaped by ideological attachment (McCright and Dunlap, 2011a,b; Mildenberger et al., 2017). To the degree that individuals have pre-existing beliefs about local climate impacts that are informed by broader climate beliefs rather than objective climate risks, it is unclear whether personalized information can overcome these ideological priors. While many individuals report that they have already experienced the effects of climate change, these perceptions may reflect a form of motivated reasoning (Howe and Leiserowitz, 2013). When individuals are provided with personal risk information, they may update their risk perceptions in either an upward or downward direction depending on an individual's level of objective risk exposure. This type of updating could either be described via the psychological mechanisms of construal theory, or could be framed as a form of direct Bayesian updating in response to new information about the nature of perceived climate risks.

In the context of these findings, it is not clear whether personalized risk messaging will have the effects on public risk attitudes that many advocates and practitioners hope. Thus, additional research is necessary to evaluate the applied impacts of common risk management techniques, especially in the context of spatially-variable threats like sea-level rise, which produces clear within-community differences in risk exposure. Unlike forms of extreme weather whose impacts will be felt more broadly, properties at the highest risk for sea-level rise can be identified in advance. Climate adaptation planners have thus been working simultaneously to raise individual-level risk awareness while also creating regional coalitions to fund adaptation measures that will mitigate the impacts of rising water levels. Correspondingly, there is an immediate need to better understand the effects of these risk messaging efforts on sea-level rise risk perceptions in vulnerable coastal areas.

3. Methods

We contracted with Qualtrics to survey households in the San Francisco Bay Area between June 5 and July 27, 2017, generating 2201 complete survey responses. We follow standard definitions of the San Francisco Bay Area to include residents of nine counties (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma) that border the Bay. Qualtrics survey response rates vary from 8-12%.

To ensure spatial coverage across all Bay Area counties, Qualtrics delivered the survey to panel respondents in every zip code in the 9-county San Francisco Bay region, using zip codes that potential survey respondents provided to Qualtrics when joining their commercial survey panel. As an additional geolocation check, we asked respondents for their zip code at the beginning of the survey using the following prompt: "In this survey, we would you like to ask you some questions about your local experiences. To let us ask you questions that are relevant to your community, please let us know your 5-digit zip code in the box below." If respondents entered a zip code lower than 94002 (the Bay Area minimum) or greater than 95694 (the Bay Area maximum), they were exited from the survey. Respondent-provided zip codes were different from Qualtrics-provided zip codes for 348 survey respondents; in addition, 45 individuals lacked a Qualtrics zip code field to allow comparison with our survey-derived zip codes. We view these differences as a likely function of individuals moving between the point where they signed up to participate in Qualtrics surveys and the point where they took our survey. For example, about 11% of the US population moved between 2015 and 2016. Our survey ultimately included respondents from 258 different Bay Area zip codes, out of 329 total zip codes in the 9 Bay Area counties (78% coverage). The number of respondents per zip code ranged from 1 to 27 (the latter in City of San Francisco zip codes 94015, 94109, and 94122). In the analysis that follows, we exclusively use respondent self-reported zip codes as the basis for our analysis. In the online SI, we visualize respondent coverage across zip codes.

In Table 1, we compare the demographics of our survey sample against population-weighted averages across all nine Bay Area counties. Bay Area demographic data is sourced from 2015 1-year American Community Survey (ACS) estimates. Our sample is skewed slightly female relative to the general Bay Area population. It also significantly under-represents Latino residents, and over-represents whites and more highly educated individuals. The results we report in this research note are a function of a randomized survey experiment; causal identification is not compromised by these sample imbalances. However, while our sample offers better representativeness than such online convenience samples as Amazon MTurk, future research may wish to evaluate how our results generalize to hard-to-contact, socioeconomically disadvantaged communities in coastal areas.

Our survey experiment instrument consisted of three parts: first, respondents were asked a battery of questions about their belief in global warming. Question wording mirrored questions used by the Yale

Table 1
Sample demographic imbalances contrasted with Bay Area estimates (population-weighted averages of 9 Bay Area counties), population 18 years and older

	Surveysample	Bay area estimate
Prop. Male	0.461	0.492
Prop. White	0.660	0.531
Prop. African-American	0.020	0.060
Prop. Hispanic	0.024	0.210
Prop. Asian-American	0.250	0.263
Prop. Less than HS	0.002	0.120
Prop. Highschool	0.030	0.176
Prop. Somecollege	0.125	0.216
Prop. Collegedegree	0.404	0.255
Prop. Grad./Prof.degree	0.340	0.168

Project on Climate Change Communication, including questions for which downscaled county-level opinion models have been made available (Howe et al., 2015; Mildenberger et al., 2017). The full text of all climate-related survey questions is provided in an online SI.

Second, respondents were divided into one of three treatment groups. A control group (n = 678) did not receive any information about their zip-level flood risk. The first treatment group (n = 692) received a map of their zip code showing the effects of 100 cm (3.2 feet) of sea-level rise. A second treatment group (n = 728) received a map of their zip code showing the effects of 100 cm (3.2 feet) of sea-level rise coupled with a 100-year storm scenario. Objective flood risk for each zip code was characterized using sea-level rise projections developed through the U.S. Geological Survey's Coastal Storm Modeling System (CoSMoS) project, which uses downscaled global wind and tide data to define regional wave and water level conditions for future sea-level rise and storm scenarios (Barnard et al., 2009, 2014). According to the recently updated California sea-level rise science guidance, by 2100 there is 67% chance of sea-level rise between 1.6and 3.4 feet above the average from 1991to 2009 (State of California, 2018). Fig. 1 provides a sample zip-level flood risk map; this map would have been shown to survey respondents assigned to the 100 cm (3.2 feet) sea-level rise treatment group who resided in zip code 94403.

Respondents in the treatment group were also provided the following caption text above and below their zip-level map. “This map shows the flooding risk in your zip code from a 1 m(3.28 feet) sea-level rise. (The map may take a few moments to load). The hatched blue lines indicate the parts of your zip code that will be flooded. If you don’t see any hatched blue lines, there will be no flooding associated with sea-level rise in your zip code. The black lines just give the boundaries of the zip code so that you can more easily find the general location of your home on this map. Please spend a few moments looking at this map. A red button will appear in a few seconds that will let you move on to the next page.” For respondents who received a map of their zip code under a combined sea-level rise/100-year storm condition, a slightly modified text was used to highlight this change (provided in the online SI). Survey respondents could not navigate away from the treatment condition map for 20 sto ensure they spent time examining the map. Note that, in both cases, respondents were not explicitly given guidance on the timing of these experienced risks. For instance, the 100-year storm condition was merely described as a“major storm.” In this way, we did not explicitly specify the temporal proximity or distance of these flood threats.

Subsequent to treatment, respondents were asked a series of questions about their perceptions of sea-level rise risks. These series of questions were designed to probe individual concerns with a sequence of increasingly “distant” impacts. Individuals were asked: “How much do you think sea-level rise will harm...” 1) “...you personally?” 2) “...people in the Bay Area” 3) “...people in the United States” 4) “...people in developing countries” and 5) “...future generations.” Respondents answered on a four point scale from “Not at all” to “A great deal”. Respondents were also asked about a willingness-to-pay measure that is described in the results section below.

For each main outcome measure, we use the following OLS regression analysis to estimate the effect of the map exposure treatment on respondent attitudes and risk perceptions:

$$\mathbb{E}(Y_i) = \alpha + \beta_1 D1_i + \beta_2 D2_i \tag{1}$$

where Y_i is the outcome measure for respondent i, $D1_i$ is an indicator variable for whether applicant i was treated with the 100 cm sea-level rise map and $D2_i$ is an indicator variable for whether an applicant was treated with the 100cm + storm surge treatment map. For Figure 4 onwards, both treatment conditions were collapsed into a single D_i that was an indicator for any treatment exposure. α represents the estimate of the mean baseline outcome for the control group. $\widehat{\beta_k}$ is the estimate of the average treatment effect of receiving a given treatment on the outcome.

For sub-group analysis, we estimate the same model, subsetted to the relevant parts of the experimental sample. We outline our question wording and coding strategy for our subgroup analyses in the Supplementary Information.

4. Results

Fig. 2 reports descriptive results of our sample's sea-level rise risk perceptions. This figure limits analysis to control group respondents (who never received any zip-level flood risk information). Among these control individuals, we find that individual respondents view themselves, personally, as least at risk from sea-level rise; they report the highest levels of perceived harm when considering future generations and developing countries. In other words, Bay Area publics still view sea-level rise as a distant threat.

We find that exposure to information about zip-level flood risks differentially shapes these varied risk perceptions, as summarized in Fig. 3. Map exposure had no effect on public perceptions of harm to future generations, developing countries or the Bay Area broadly. However, map exposure did slightly increase respondent perceptions of harm by sea-level rise to people in the United States overall. Most significantly, exposure to a zip-level flooding map substantially *decreased* respondent concern that sea-level rise would generate personal harm.

We did not observe significantly different effects between the map treatments based on 100 cm (3.2 feet) sea-level rise alone versus treatments that also included flooding risk from a 100-year storm surge combined with baseline 100 cm (3.2 feet) sea-level rise. In the analyses that follow, we collapse both treatment conditions together into a single measure of whether respondents were treated with any zip-level flood risk map.

Previous research has emphasized the role of climate beliefs in shaping risk perceptions (Goebbert et al., 2012; Howe and Leiserowitz, 2013; Hamilton and Stampone, 2013; Broomell et al., 2017). For instance, Howe and Leiserowitz (2013) find that prior beliefs about climate change shape individual-level processing of local weather experiences. Correspondingly, does an individual's pre-treatment belief in global warming shape their map exposure responsiveness? Fig. 4 shows that the observed decrease in post-treatment concern with sea-level rise is largely driven by individuals who believe in climate change. By contrast, climate change disbelievers did not respond to map exposure by updating their personal sea-level rise risk perceptions.

Relatedly, we can also evaluate differences in map responsiveness as a function of ideology, given that ideology has become an important predictor of US climate beliefs (McCright and Dunlap, 2011b). Fig. 5 charts these effects. We do find sustained decrease in concern among liberal, moderate and conservative populations (though the effect is more pronounced among moderates and liberals). Intriguingly, the strongest (and only significant) subgroup increase in perceptions that Americans will be harmed by sea-level rise comes from the conservative

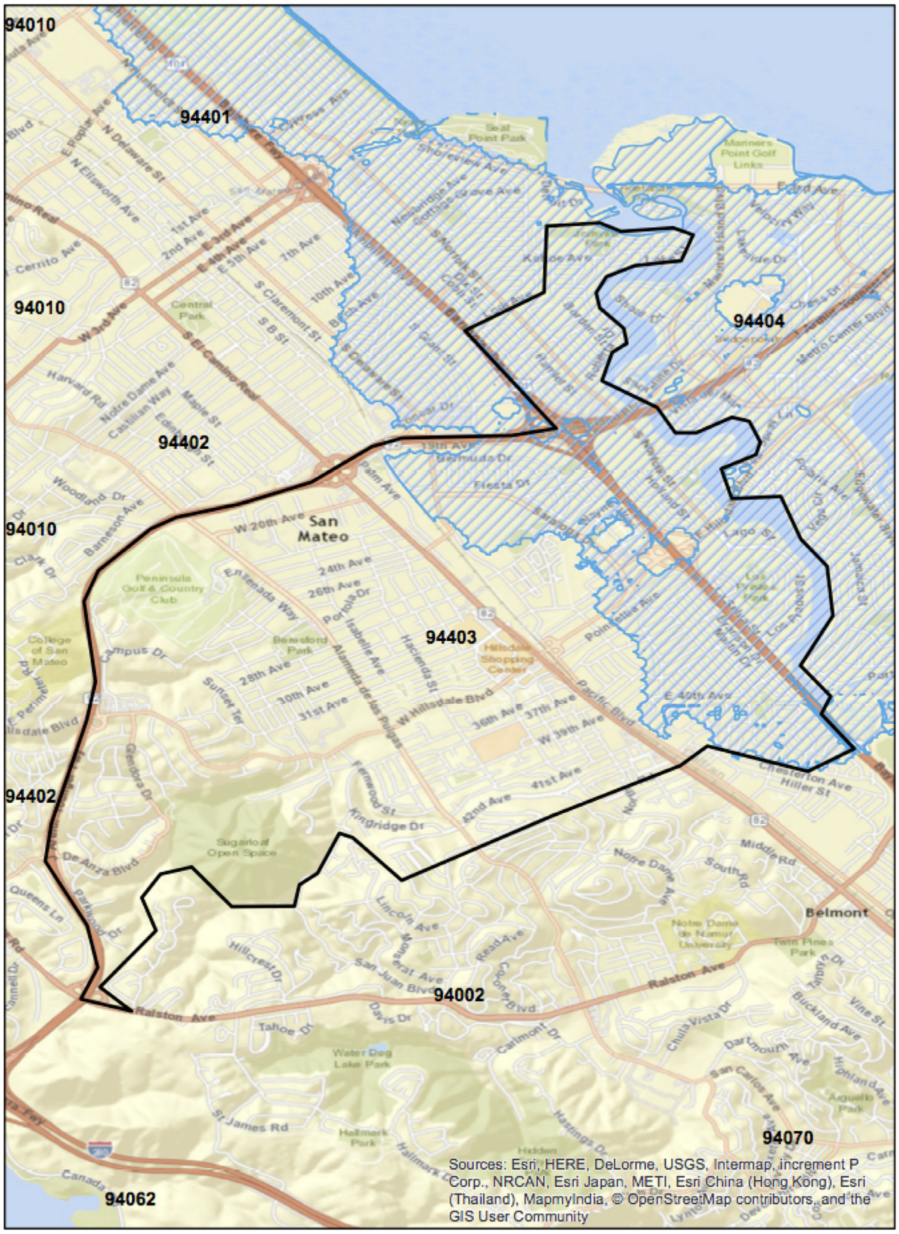

Fig. 1. Example map, provided to individuals in the treatment group who reside in Bay Area zip code 94403 that shows the extent of sea-level rise under a 100cm (3.2 feet) scenario.

subgroup.

4.1. Linking Objective and Subjective Flood Risk

Is map exposure responsiveness heterogeneous across respondents' objective climate risks? In Fig. 6, we divide survey respondents by their zip-level flood risk. First, we determine the percentage of the area of each zip code which will be inundated under a 100 cm sea-level rise scenario, considering both no storm and a 100-year storm, by overlaying the zip code locations with the CoSMoS flood hazard predictions. This gives a quantitative measure of the spatial impact of flooding in each zip code. We divide zip codes into groupings based on this measure: zip codes with no projected flooding, zip codes with any projected flooding (n = 88), zip codes where more than10% of the area is projected to flood (n = 54), zip codes where more than 20% of the area is projected to flood (n = 35), zip codes where more than 30% of the area is projected to flood (n = 27) and zip codes where more than 40% of the area is projected to flood (n = 17). As we subset these zip codes into smaller groups that have objectively higher risks, both the zip code sample size and respondent sample size decline substantially, increasing uncertainty in our estimates. Nonetheless, respondents in all but the"NO FLOOD" condition would have received a zip-level flood risk map that included a mapping of some local flooding threats.

In all but the small subset of zipcodes where more than 40% of the area is projected to flood, receiving the map either leaves a respondent's personal risk perceptions unchanged or reduces these perceptions. This suggests that, for most respondents, personalized risk maps at best validate pre-existing risk perceptions. Surprisingly, many individuals who receive a map showing that a part of their zip code is projected to flood (e.g. the ANY FLOOD condition in Fig. 6), personal risk perceptions may still decline significantly as a function of treatment exposure.

4.2. Willingness topay for climate adaptation measures

While provision of personalized risk information may have reshaped respondent concerns about sea-level rise, changes in individual

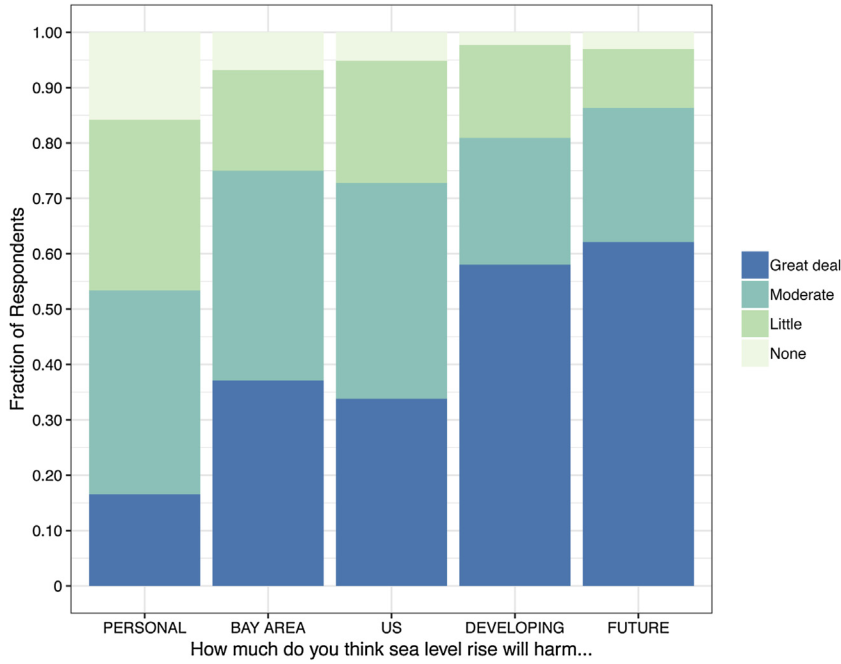

Fig. 2. Concern about sea-level among Bay Area survey sample (Control-group respondents only).

perceptions may not automatically translate into differentiated willingness-to-pay for group-level climate adaptation measures. This is of particular interest since the map exposure treatment did not shape overall perceptions of how much Bay Area residents would be impacted by sea-level rise. In other words, even when individuals reduce personal concern that sea-level rise will harm them, they may still hold onto pro-social policy preferences and maintain their willingness to support costly adaptation measures.

We evaluate this willingness-to-pay (WTP) for climate adaptation measures using a contingent valuation approach. Contingent valuation methods present individuals with a hypothetical scenario and queries how much an individual is willing to pay for some good or service. Some economists criticize contingent valuations as flawed because they rely on hypothetical scenarios rather than observed behavior (Diamond and Hausman, 1994; Hausman, 2012). However, contingent valuation is often the best available WTP technique when behavioral data is unfeasible or unavailable; this approach has been used extensively by environmental economists in both academic and regulatory spheres (e.g., Kotchen et al., 2017).

Our WTP instrument comprises two parts. First, we inform survey respondents about the recent passage of ballot Measure AA to fund the San Francisco Bay Clean Water, Pollution Prevention and Habitat Restoration Program. This initiative restored wetlands across the Bay Area through a $12 annual land parcel tax, offering substantial climate adaptation benefits. Second, we then asked respondents "If another ballot initiative was offered for a parcel tax of [MONEY AMOUNT] per

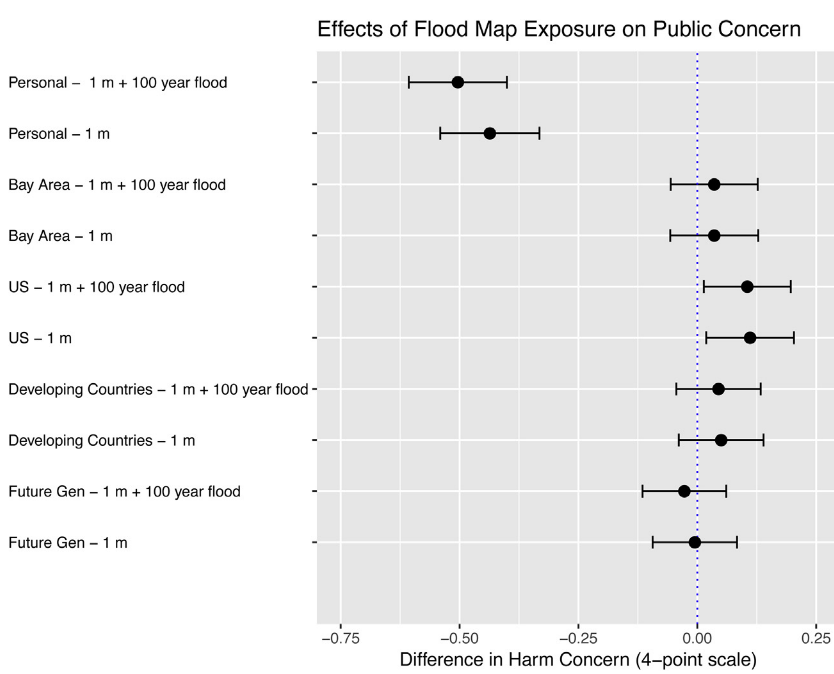

Fig. 3. Effect of exposure to zip-level sea-level rise flooding map on sea-level rise risk perceptions.

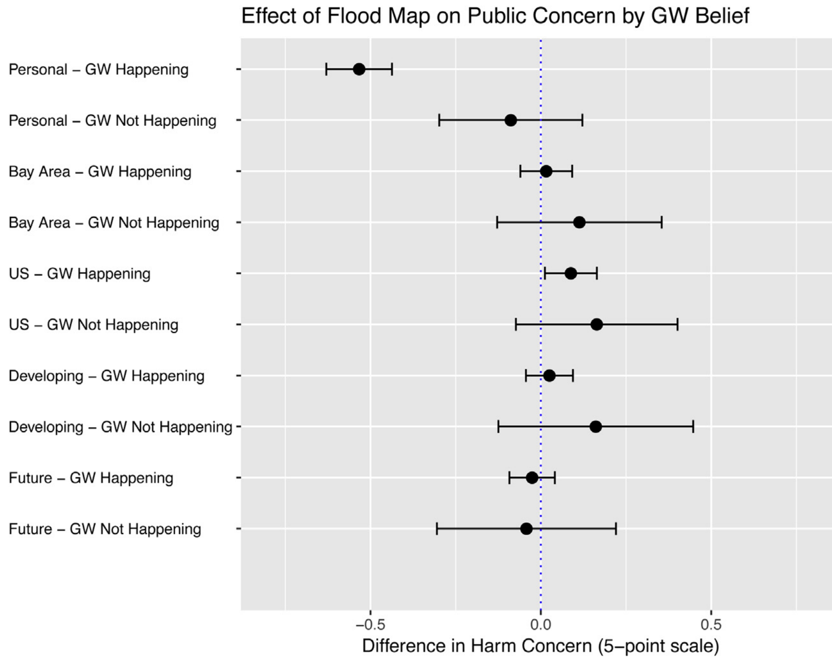

Fig. 4. Effect of exposure to zip-level sea-level rise flooding map on sea-level rise risk perceptions, by respondent belief in climate change.

year to [USE CASE], would you support this ballot measure or not?" We randomly assigned respondents to a dollar amount("MONEY AMOUNT") from the following sequence: \$1, \$2, \$5, \$10, \$20, \$50, \$100. In total, $n = 293$ received a scenario asking them about a \$1 willingness-to-pay, $n = 336$ received a \$2 scenario, $n = 282$ received a \$5 scenario, $n = 308$ received a \$10 scenario, $n = 269$ received a \$20 scenario, $n = 302$ received a \$50 scenario, and $n = 308$ received a \$100 scenario. We also randomized the intended use of the ballot measure funds("USE CASE"), either to "build flood control infrastructure", to "prevent the impacts of sea-level rise", or to "support wetlands restoration". However, we found null results with respect to the randomized intended use of measure funds. Respondents across all use case conditions were equally likely to support the ballot measure.

To estimate WTP, we modelled support for the future ballot measure as a function of dollar amount (e.g. the randomized cost of the measure) as well as gender, race, education, ideology, the total housing value in a respondent's zip code threatened by sea-level rise (variable construction described in the online SI), and respondent belief in climate change. We use a multivariate logit analysis estimating—separately for treatment and control group—the marginal effect of the presented dollar amount ("the bid price") on support for the proposed ballot measure.

We find a negative, statistically significant effect of proposed cost on measure support in both the treatment and control groups. Among treated individuals, a \$4.76 increase in the cost of the proposed ballot measure was linked to a 1% reduction in the probability that respondents supported the proposal. Among control individuals, a 1%

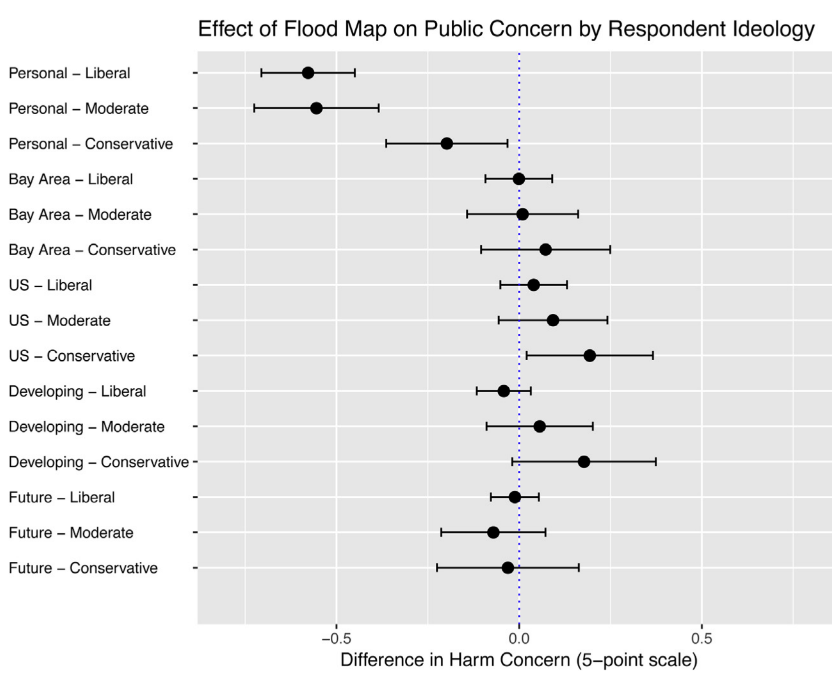

Fig. 5. Effect of exposure to zip-level sea-level rise flooding map on sea-level rise risk perceptions, by respondent ideology.

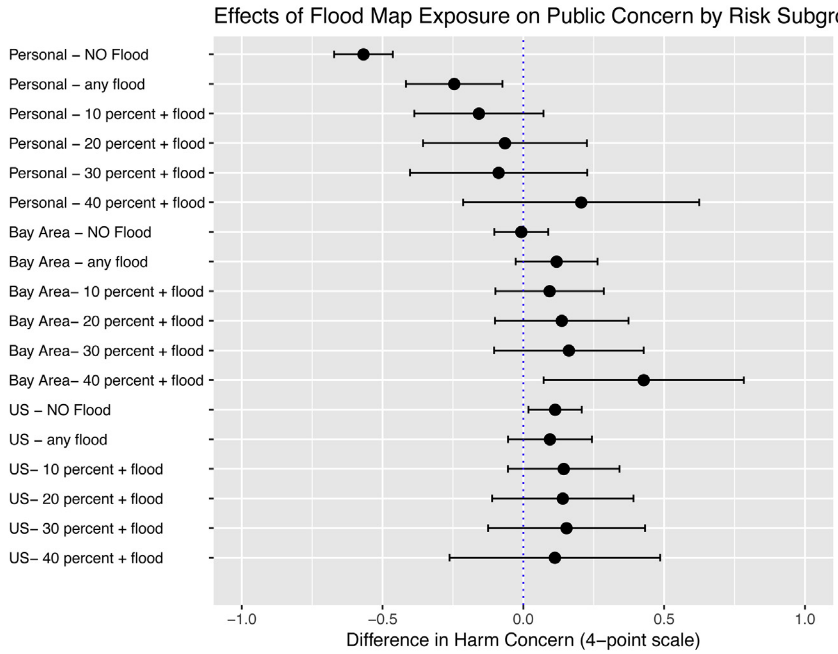

Fig. 6. Effect of exposure to zip-level sea-level rise flooding map on sea-level rise risk perceptions, by presence of flooding, subsetted by the fraction of a given zip code's area that is projected to flood.

reduction in measure support was associated with a $4.00 increase in cost. We use the R package 'DChoice' throughout to analyze our willingness-to-pay measure. For more information on the methods and procedures, see Nakatani et al., 2016. These treatment and control group marginal effects were not statistically different from one another, so we cannot reject the null that treatment and control groups have the same WTP. We also find significant marginal effects with respect to a series of other control variables. As detailed in the online SI, willingness to pay is significantly increasing in belief in climate change and more liberal ideological positioning. We can also calculate the average willingness-to-pay among both treated and control subpopulations under a range of assumptions. If we assume the error distribution is truncated at the maximum bid amount, the mean WTP is $58.69 in the treatment group and $58.83 in the control group. These WTP estimates vary over different techniques for generating willingness to pay estimates. However, in all cases, the estimates for treatment and control groups closely track one another. Again, we cannot reject the null effect and it does not appear the risk map exposure shaped support for the measure.

5. Discussion

Our results provide a rigorous empirical evaluation of how personalized risk messages may influence perceptions of sea-level rise risk. In line with previous research, we find that sea-level rise is not viewed as an immediate threat for many Bay Area residents; the majority believe it will not harm them personally and that the most significant harm will be experienced by future generations and developing countries. At the same time, our results suggest that providing individuals with personalized risk messages has, at best, uneven effects on sea-level rise risk perceptions. In contradiction to many advocates' presumptions, we find that providing residents with personalized flood risk maps may *decrease* respondents' sea-level rise concerns. These negative effects are somewhat moderated among respondents whose zip code is projected to experience extreme flooding threats; yet, many individuals living in zip codes where some flooding is projected still reduce their personal sea-level rise concerns after exposure to a zip-code level flooding map. We further found that these effects are concentrated among individuals who already believe in climate change. Encouragingly, negative responses to flooding risk maps did not translate into a reduced willingness-to-pay for proposed climate adaptation infrastructure.

Our research cannot conclusively adjudicate between the diverse mechanisms that might explain this surprising set of effects. One explanation could be that respondents engage in Bayesian updating when exposed to personalized risk maps. Individuals who believe in climate change may have assumed they were more at risk than these maps suggest; as a result, they update their sense of personal vulnerability post-treatment. In other words, individuals may rely on their pre-existing beliefs about climate change to inform evaluations of personal harm. Once an individual discovers more specific local information, this new information about "whether their feet will be wet" displaces more generalized risk perceptions.

Yet, we also view these results as consistent with predictions made by construal-level theory. From this perspective, increasing the psychological proximity of a threat may reduce the relevance of abstract threat dimensions. For example, in the absence of specific information about local flooding, individuals may rely on their strong climate change beliefs to inform sea-level rise risk perceptions. But when confronted with more specific information, those same individuals may begin to process the sea-level rise threat in the context of different emotional and cognitive considerations, and fixate more on specific local risk factors.

Our results thus present a range of intriguing options for future research. First, our results challenge assumptions that advocates have made about the optimal style of climate risk communication. Instead, scholars and advocates may find that other types of visual risk messaging provide the public with more appropriate risk impressions. For example, methods that highlight potential impacts on local infrastructure, economic opportunities, and public spaces, may have a different effect than our experimental maps. In this way, we might want to test the effects of presenting individuals with images of local flooding in areas that they know or care about, such as specific roadways or parklands; this possibility would be consistent with a literature that emphasizes the importance of presenting risks to "iconic" places (Shaw et al., 2009). Similarly, scholars may want to explore how, as prospect theory suggests, different gain or loss frames can be interwoven with visual imagery to strengthen or moderate its effect. Finally, scholars will want to more deeply explore these differentiated effects risk communications by partisan and ideological subgroups.

Efforts to inform people about the indirect effects of climate risks, such as increased travel times to work or loss of critical infrastructure like sewage treatment or electricity, also deserve rigorous empirical testing. In the example of sea-level rise, coastal flooding will damage infrastructure in ways that ripple through a much broader population (Hummel et al., 2018). Communicating these effects may moderate respondents' potential focus on their own individual property. Finally, we should consider whether the visual components of risk maps can be improved. We know that some respondents struggle to understand maps with risk information (Haynes et al., 2007), which has led to research on optimizing maps for communication purposes (Van Kerkvoorde et al., 2018). In our view, the maps in our experiment do provide clear information at the granular level to survey respondents. We believe most respondents could place themselves on our map given its high resolution. However, this is an assumption that should be empirically tested in future research. In addition, finer spatial resolution would be helpful to better unpack the link between subjective and objective flood risk, suggesting the importance of more research on neighbourhood-scale risk perceptions.

Our priority in this paper has been to evaluate a common risk communication strategy, rather than explore the psychological microfoundations of risk perceptions. Yet, our findings emphasize the importance of continuing to unpack these mechanisms. This deeper understanding is all the more important because of the large policy stakes. Regional-scale efforts to map sea-level rise inundation hazards have become popular. However, while useful to decision-makers, these may not be as effective as often assumed in increasing public concern about sea-level rise.

Finally, comparative research is needed to ascertain whether the same types of processes affect sea-level rise risk perceptions among citizens in other parts of the country, in rural versus urban areas, and in other regions of the world that are also vulnerable to sea-level rise. This promises to be particularly interesting for regions with different political cultures or in areas predicted to experience more severe sea-level rise (e.g., Miami, Florida) or that have experienced an extreme storm event potentially related to climate change (e.g., New York/New Jersey and Superstorm Sandy or Houston and Hurricane Harvey). Far from being a theoretical debate, this knowledge is vital for practitioners, policymakers and community leaders as they work to protect citizens around the world from the worst impacts of climate change. Our shared ability to communicate climate risks across space and time is necessary to protect the social and economic livelihood of global publics. This means that scholars must do their part to rigorously evaluate the ability of popular climate communication tools to support local decision-making and adaptation.

Appendix A. Supplementary Data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gloenvcha.2019.01.002.

References

Abatzoglou, J.T., Williams, A.P., 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proc. Natl. Acad. Sci. 113 (42), 11770–11775.

Akerlof, K., et al., 2013. Do people "personally experience" global warming, and if so how, and does it matter? Global Environ. Change 23 (1), 81–91.

Barnard, P.L., O'Reilly, B., et al., 2009. The Framework of a Coastal Hazards Model- A Tool for Predicting the Impact of Severe Storms. U.S. Geological Survey Tech. rep.

Barnard, P.L., van Ormondt, M., et al., 2014. Development of the Coastal Storm Modeling System (CoSMoS) for predicting the impact of storms on high-energy, active-margin coasts. Nat. Hazards 74 (2), 1095–1125.

Birkholz, S., et al., 2014. Rethinking the relationship between flood risk perception and flood management. Sci. Total Environ. 478, 12–20.

Brody, S., Grover, H., Vedlitz, A., 2012. Examining the willingness of Americans to alter behaviour to mitigate climate change. Clim. Policy 12 (1), 1–22.

Broomell, S.B., Winkles, J.-F., Kane, P.B., 2017. Theperception of daily temperatures as evidence of global warming. Weather Clim. Soc. 9 (3), 563–574.

Brügger, A., Dessai, S., et al., 2015a. Psychological responses to the proximity of climate change. Nat. Clim. Change 5 (12), 1031.

Brügger, A., Morton, T.A., Dessai, S., 2015b. Hand in hand: Public endorsement of climate change mitigation and adaptation. PLoSONE 10 (4), e0124843.

Brügger, A., Morton, T.A., Dessai, S., 2016. Proximising" climate change reconsidered: A construal level theory perspective. J. Environ. Psychol. 46, 125–142.

Church, J.A., White, N.J., 2006. A 20th century acceleration in global sea-level rise. Geophys. Res. Lett. 33 (1).

Devine-Wright, P., 2013. Think global, act local? The relevance of place attachments and place identities in a climate changed world. Global Environ. Change 23 (1), 61–69.

Diamond, P.A., Hausman, J.A., 1994. Contingent valuation: is some number better than no number? J. Econ. Perspect. 8 (4), 45–64.

Gifford, R., et al., 2009. Temporal pessimism and spatial optimism in environmental assessments: An 18-nation study. J. Environ. Psychol. 29 (1), 1–12.

Goebbert, K., et al., 2012. Weather, climate, and worldviews: The sources and consequences of public perceptions of changes in local weather patterns. WeatherClimate Soc. 4 (2), 132–144.

Haden, V.R., et al., 2012. Global and local concerns: what attitudes and beliefs motivate farmers to mitigate and adapt to climate change? PLoS ONE 7 (12), e52882.

Hamilton, L.C., Stampone, M.D., 2013. Blowin'in the wind: Short-term weather and belief in anthropogenic climate change. WeatherClim. Soc. 5 (2), 112–119.

Hansen, J., Sato, M., Ruedy, R., 2012. Perception of climate change. Proc. Natl. Acad. Sci. 109 (37), E2415–E2423.

Hauer, M.E., Evans, J.M., Mishra, D.R., 2016. Millions projected to be at risk from sea-level rise in the continental United States. Nat. Clim. Change 6 (7), 691–695.

Hausman, J., 2012. Contingent valuation: from dubious to hopeless. J. Econ. Perspect. 26 (4), 43–56.

Haynes, K., Barclay, J., Pidgeon, N., 2007. Volcanic hazard communication using maps: an evaluation of their effectiveness. Bull. Volcanol. 70 (2), 123–138.

Hinkel, J., et al., 2014. Coastal flood damage and adaptation costs under 21st century sea-level rise. Proc. Natl. Acad. Sci. 111 (9), 3292–3297.

Howe, P.D., Leiserowitz, A., 2013. Who remembers a hot summer or a cold winter? The asymmetric effect of beliefs about global warming on perceptions of local climate conditions in the US. GlobalEnviron. Change 23 (6), 1488–1500.

Howe, P.D., Mildenberger, M., et al., 2015. Geographic variation in opinions on climate change at state and local scales in the USA. Nat. Climate Change 5 (6), 596–603.

Hummel, M.A., Berry, M.S., Stacey, M.T., 2018. Sea level rise impacts on wastewater treatment systems along the US coasts. Earth's Future.

IPCC, 2013. Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Kellens, W., Terpstra, T., De Maeyer, P., 2013. Perception and communication of flood risks: a systematic review of empirical research. Risk Anal. 33 (1), 24–49.

Kotchen, M.J., Turk, Z.M., Leiserowitz, A., 2017. Public willingness to pay for a US carbon tax and preferences for spending the revenue. Environ. Res. Lett. 12 (9), 094012.

Ledgerwood, A., Trope, Y., Chaiken, S., 2010a. Flexibility now, consistency later: Psychological distance and construal shape evaluative responding. J. Personality Soc. Psychol. 99 (1), 32.

Ledgerwood, A., Wakslak, C.J., Wang, M.A., 2010b. Differential information use for near and distant decisions. J. Exp. Soc. Psychol. 46 (4), 638–642.

Leiserowitz, A., 2006. Climate change risk perception and policy preferences:the role of affect, imagery, and values. Clim. Change 77 (1-2), 45–72.

Leiserowitz, A., et al., 2017. Climate change in the American mind: October 2017. Yale Program on Climate Change Communication.

Leviston, Z., Price, J., Bishop, B., 2014. Imagining climate change: The role of implicit associations and affective psychological distancing in climate change responses. Eur. J. Soc. Psychol. 44 (5), 441–454.

Liberman, N., Trope, Y., 2008. The psychology of transcending the here and now. Science 322 (5905), 1201–1205.

Lorenzoni, I., Nicholson-Cole, S., Whitmarsh, L., 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. GlobalEnviron. change 17 (3), 445–459.

Lorenzoni, I., Pidgeon, N., 2006. Public views on climate change: European and USA perspectives. Clim. Change 77 (1-2), 73–95.

Lubell, M., 2017. The governance gap: Climate adaptation and sea-level rise in the San Francisco Bay area. UC Davis Center for Environmental Policy and Behavior Research Brief.

Lujala, P., Lein, H., Rød, J.K., 2015. Climate change, natural hazards, and risk perception: the role of proximity and personal experience. Local Environ. 20 (4), 489–509.

Mann, M.E., et al., 2017. Influence ofanthropogenic climate change on planetary wave resonance and extreme weather events. Sci. Rep. 7.

McCright, A.M., Dunlap, R.E., 2011a. Cool dudes: The denial of climate change among conservative white males in the United States. GlobalEnviron. Change 21 (4), 1163–1172.

McCright, A.M., Dunlap, R.E., 2011b. The politicization of climate change and polarization in the American public's views of global warming, 2001-2010. Sociol. Quart. 52 (2), 155–194.

McDonald, R.I., Chai, H.Y., Newell, B.R., 2015. Personal experience and the 'psychological distance' of climate change: An integrative review. J. Environ. Psychol. 44, 109–118.

Meehl, G.A., et al., 2005. How much more global warming and sea level rise? Science 307 (5716), 1769–1772.

Mildenberger, M., et al., 2017. The spatial distribution of Republican and Democratic climate opinions at state and local scales. Clim. Change 145 (3-4), 539–548.

Moser, S.C., Dilling, L., 2007. Toward the social tipping point: Creating a climate for change. Creating a climate for change: Communicating climate change and facilitating social change 491–516.

Myers, T.A., et al., 2013. The relationship between personal experience and belief in the reality of global warming. Nat. Clim. Change 3 (4), 343.
Nakatani, T., Aizaki, H., Sato, K., 2016. DChoice: Analyzing Dichotomous Choice Contingent Valuation Data. R package version 0.0.15.
O'Connor, R.E., Bard, R.J., Fisher, A., 1999. Risk perceptions, general environmental beliefs, and willingness to address climate change. RiskAnal. 19 (3), 461–471.
O'Neill, S., Nicholson-Cole, S., 2009. Fear Won't Do It"promoting positive engagement with climate change through visual and iconic representations. Sci. Commun. 30 (3), 355–379.
Rayner, S., Malone, E.L., 1997. Zen and the art of climate maintenance. Nature 390 (6658), 332.
Reed, A.J., et al., 2015. Increased threat of tropical cyclones and coastal flooding to New York City during the anthropogenic era. Proc. Natl. Acad. Sci. 112 (41), 12610–12615.
Scannell, L., Gifford, R., 2013. Personally relevant climate change: The role of place attachment and local versus global message framing in engagement. Environ. Behav. 45 (1), 60–85.
Schoenefeld, J.J., McCauley, M.R., 2016. Local is not always better: the impact of climate information on values, behavior and policy support. J. Environ. Stud. Sci. 6 (4), 724–732.
Schuldt, J.P., Rickard, L.N., Yang, Z.J., 2018. Does reduced psychological distance increase climate engagement? On the limits of localizing climate change. J. Environ. Psychol. 55, 147–153.
Shaw, A., et al., 2009. Making local futures tangible—synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building. Global Environ. Change 19 (4), 447–463.
Shwom, R., Dan, A., Dietz, T., 2008. The effects of information and state of residence on climate change policy preferences. Clim. Change 90 (4), 343–358.
Smith, J.M., et al., 2010. Potential impact of sea level rise on coastal surges in southeast Louisiana. Ocean Eng. 37 (1), 37–47.
Spence, A., Pidgeon, N., 2010. Framing and communicating climate change: The effects of distance and outcome frame manipulations. Global Environ. Change 20 (4), 656–667.
Spence, A., Poortinga, W., Butler, C., et al., 2011. Perceptions of climate change and willingness to save energy related to flood experience. Nat. Clim. change 1 (1), 46.
Spence, A., Poortinga, W., Pidgeon, N., 2012. The psychological distance of climate change. RiskAnal. 32 (6), 957–972.
Strauss, B.H., Kulp, S., Levermann, A., 2015. Carbon choices determine US cities committed to futures below sea level. Proc. Natl. Acad. Sci. 112 (44), 13508–13513.
Sweet, W.V., 2014. Sea level rise and nuisance flood frequency changes around the United States. US Department of Commerce, National Oceanic, Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products, and Services.
Trope, Y., Liberman, N., 2003. Temporal construal. Psychol. Rev. 110 (3), 403.
Van Kerkvoorde, M., et al., 2018. Evaluation of web maps for the communication of flood risks to the public in Europe. Int. J. Cartography 4 (1), 49–64.
Warrick, R., Oerlemans, J., 1990. SeaLevel Rise. Cambridge University Press.
Weber, E.U., 2006. Experience-based and description-based perceptions of long-term risk: Why global warming does not scare us (yet). Clim. change 77 (1-2), 103–120.
Witte, K., Allen, M., 2000. A meta-analysis of fear appeals: Implications for effective public health campaigns. HealthEduc. Behav. 27 (5), 591–615.